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L. Odud

National University of Water and Environmental Engineering, Rivne, Ukraine

EXPANDED POLYSTYRENE IN WATER SOFTENING TECHNOLOGIES

Water plays a huge role in life of human beings: daily for living and economic growth. Its quality has big impact depending on using purposes. Softening is one of main treatment of water for industrial needs. Existing water softening edifices productivity is lower than designed, because of industry level decreasing. Important questions rise of exploitation new, improving present water softening methods. Using expanded polystyrene backfill is already well known for clarifying, discoloration and deferrization. In this paper we propose applying expanded polystyrene filters with an increased layer of suspended sediment in water softening technologies combining it with liming method. Results we've reached showing great perspectives for simplification of existing water softening technological scheme, excluding clarifiers with suspended sediment.

Keywords: *water hardness, water softening, expanded polystyrene filling, suspended sediment layer, liming method.*

Problem formulation

Water has always played a key role in economic development, and economic development has always been accompanied by water development. After agriculture, the two major users of water for development are industry and energy (20% of total water withdrawals), which are transforming the patterns of water use in emerging market economies (UNESCO 2009).

Water is used by industry in multiple ways: for cleaning, heating and cooling; for generating steam; for transporting dissolved substances or particulates; as a raw material; as a solvent; and as a constituent part of products (as in the beverage industry). Different industries demand different water quality (the high-technology industry requires water of a higher quality than drinking water) and quantities. The diminishing quality of water supplies, increasing costs of water purchases and strict environmental effluent standards are forcing industries to target greater water efficiency and report on their progress (UNESCO 2009).

In general water treatment for industrial purposes starts with mechanical purification. Then water passes the main stage: softening (removal of temporary hardness salts) and desalination (removal of constant hardness salts). The final stage is decontamination (removal of dissolved in water gases) (Zguro et al. 2012).

Hardness is an important water quality parameter determining the suitability of water for domestic and industrial uses. Hard water contains high levels of different types of polyvalent ions, mainly magnesium and calcium. Hard water causes scaling on membranes, pipes, and hot boilers. Also causes valves to stick due to the formation of calcium carbonate deposits and leave stains in plumbing fittings (Estape, 2014).

Water softening is the process of extracting calcium and magnesium ions from water to make it be possible to use for different proposes. The most used reagent treatment method for water softening is liming (Huchler, 2007). The lime softening process removes hardness by chemical precipitation, followed by sedimentation and filtration, therefore showing similarities to the conventional chemical clarification process. A single stage lime softening plant consists of a primary clarifier and filtration step. Lime, caustic soda (sodium hydroxide) or soda ash is added to the water, increasing the pH, which causes the metal ions to flocculate and precipitate. The metal precipitates are removed during the sedimentation stage, prior to filtration. Other contaminants may also combine with the precipitates and be removed by this process (Ministry of Health 2016).

As development, assemblage and application of main device (clarifier with suspended sediment) is quite difficult and also nowadays existing edifices work with much lower productivity than designed. Thus, it is very important to optimize existing methods as well as explore new ways of water softening. Using expanded polystyrene filters with an increased layer of suspended sediment water softening technological schemes may solve a number of questions.

Analysis of recent research and publications

Filtration is typically a tertiary treatment step located downstream of secondary processes. It's primary goal is removing suspended solids from a secondary, coagulation-flocculation, or tertiary sedimentation process effluent. Many types of media can be used for filtration. In addition to traditional granular media (typically sand and anthracite), natural or synthetic fiber or fabric, synthetic fuzzy balls and beads, and other filtration media are available (WEF 2007).

A floating granular filling with expanded polystyrene was first presented at the Water Supply and Drilling Department, Ukrainian Institute of Engineers of Water Management (now – National University of Water and Environmental Engineering). Filter filling (polystyrene foam) is obtained from the marketable product of polystyrene by processing it with hot water or steam. Polystyrene sinks in water but after processing by steam or hot water it becomes floatable having a density of 0.02-0.10 $t \cdot m^{-3}$. There is the permission of the Ministry of Health (Vodopostachannya. Zovnishni merezi ta sporudi. Normi proektuvannya, 2013) for the use of polystyrene as filter filling in drinking water treatment (Orlov et al. 2016). Polystyrene foam filling in filters with ascending filtering can be single-layer or two-layer. Polystyrene foam in filters is held in a flooded state with a special lattice. Raw water is pumped through the pipeline in the bottom distribution system, passes a layer of polystyrene foam filling and cleared gathers in the top part of the filter (Orlov et al. 2014). Filter containing polystyrene granules as filter medium, have the potential to decrease water consumption and allow the construction of reservoirs with a lower hydraulic load (Schöntag et al. 2015).

There is such kind of filters as expanded polystyrene filters with an increased layer of suspended sediment. Here, ascending type of filtration allows to use an under and over filtering area and, also, it is possible to accumulate sediment in the under filtering area, which may have positive impacts on removing coarse particulate. The first who investigate and study this type of filter were Professor Valerii Orlov and Associate Professor Sergii Martynov. Their work describes the utilization of these filters for the removal of iron from water (Orlov et al. 1999). They developed and scientifically substantiated an iron removal technology used for underground water with high concentration of iron by using expanded polystyrene filters with an increased layer of suspended sediment, that allowed to intensify the process of iron removal from water, increase efficiency, extend the range of use of groundwater containing iron compounds (Martynov, 2001).

Presenting main material

Methods that we used in our work are: theoretical – analysis of existing water softening technologies, experimental – based on an experiment, that is scientific aimed experience or phenomenon observation in conditions, that accurately taken into account and that allow to monitor its progress, manage it, play it every time you repeat these conditions, analytical and statistical – evaluation of the results received in laboratory and industrial conditions and their mathematical processing.

Experimental research consists in using reagent - lime solution, and expanded polystyrene granules for water softening. Water mixes with lime in the contact tube and then through a layer of suspended sediment which is performed gradually increasing, and after that passes through floating expanded polystyrene backfill. To get the needed purifying effect it is necessary to maintain pH in mixing zone within 9,0 – 10,5 (Orlov et al., 2013).

Suspended sediment is a polydisperse system in which the rate of particles precipitation depends on the volumetric sediment concentration. The chemical composition of sediment consists of calcium carbonate and magnesium hydroxide compounds. Calcium carbonate has characteristic of condensation-crystallization structure. Magnesium hydroxide relates to the coagulation type. Magnesium hydroxide prevents direct connection and growth of calcium carbonate (Kurgaev, 1977). Forming of suspended sediment layer and getting the needed effect takes time. To create the necessary conditions for sediment work firstly we should start with lower flow rate and increase the reagent doses.

Research of softening process was held on experimental plant. It is presented on the Fig.1.

Fig. 1. Experimental plant for research of softening process

During filtering cycles we planned to control filtering rate, pressure losses and analytical characteristics of water: pH, total hardness and alkalinity.

Filtering rate can be determined by the equation 1:

$$V_f = \frac{3.6 \cdot q_{i.w.}}{f_c}, \text{ l/s} \qquad (1)$$

where f_c – filter column square, m^2; $q_{i.w.}$ – quantity of initial water, l/s.

This quantity $q_{i.w.}$ can be determined by volumetric method using a stopwatch and a measuring cylinder with a capacity of 500 ml.

Pressure losses on the filter filling during the filtering cycle can be determined with using the piezometers, the end of one tube is connected to the bottom of the filtering column, and the end of the other - to the bottom of the rinse tank (2):

$$h = P_1 - P_2, \text{ m} \qquad (2)$$

where P_1, P_2 – piezometers value, accordingly №1 and №2.

To get total hardness and alkalinity values we used complexometric method.

For total hardness determination we put 100 ml of investigated water sample in volumetric flask. Then we add there 5 ml of ammonia buffer and a bit of indicator "Eriohrom black T". Mix well till dissolving of crystals and appearance of violet color. Then we titrate the resulting solution by adding trilon B (0.1 n) till appearance of blue color. The quantity of trilon B (0.1 n) in ml will be the total hardness value.

For alkalinity determination we take 100 ml of investigated water sample and mix it with indicator "Methyl orange" till appearance of yellow color. Then titrate the mixture by adding hydrochlorid acid till color changing to bright orange.

The pH level determination was held with using ionizer EV-74. Device is represented on the Fig.2.

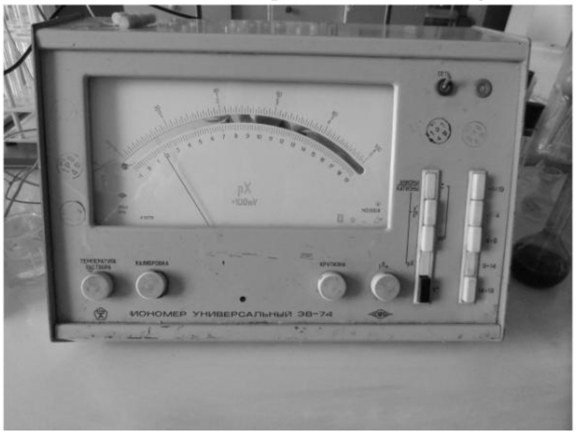

Fig. 2. Ionizer EV-74 for pH level determination.

During our research the filtering rate range was between 2,5 and 4,5 m³/hour. Filtering duration range was between 8 and 24 hours. As reagent we used lime slaked quicklime OP-1 ISO B V.2.7-90-99 ("Ferezit", Lviv). The active part of the used lime was 57,6 %. For the effective water softening process it is necessary to maintain a pH level of ≥9.0. The average indeces of initial water for the whole research period were: total hardness – 5,8 mmol/dm^3, calcium hardness – 4,25 mmol/dm^3, alkalinity – 6,10 mmol/dm^3, pH – 7,40.

Influent water containing lime is evenly distributed in the filtration device and diffuses through the two-layer filtration system, with the first layer composed of suspended sediment and the second layer of expanded polystyrene filling. After the filtration process, purified water is accumulated and extracted from the filter.

Water sampling was carried out through samplers. The amount of water collected by samplers did not exceed 5% of the total consumption that passed through the expanded polystyrene filter.

The average pH level of softened water was 9,9, what exceed pH level of initial water for 32 % in average and 56% maximum. The average decrease effect of total hardness was 66 %, maximum – 83 %. The average decrease effect of alkalinity was 64 %, maximum – 76 %.

On the Fig. 3 it's shown change of pH level, on Fig. 4 and 5 – total hardness and alkalinity reducing during filtering cycles with different filtering rates.

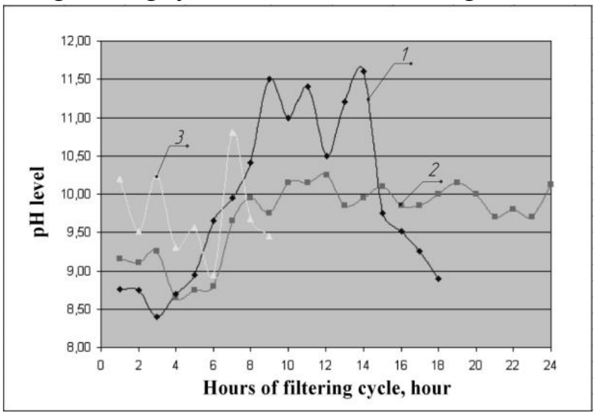

Fig. 3. Change of pH level during filtering cycles with filtering rate and duration: 1 – 2,5 m³/hour, 16 hours; 2 – 3,5 m³/hour, 24 hours; 3 – 4,5 m³/hour, 8 hours.

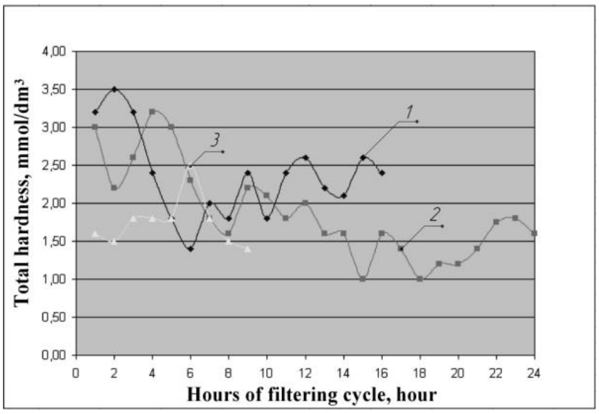

Fig. 4. Total hardness reducing during filtering cycles with filtering rate and duration: 1 – 2,5 m³/hour, 16 hours; 2 – 3,5 m³/hour, 24 hours; 3 – 4,5 m³/hour, 8 hours.

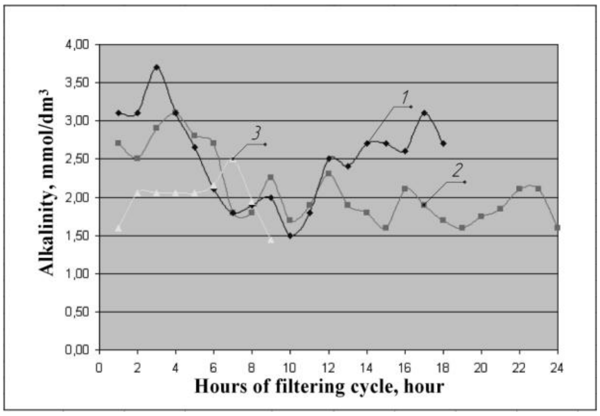

Fig. 5. Alkalinity reducing during filtering cycles with filtering rate and duration: 1 – 2,5 m³/hour, 16 hours; 2 – 3,5 m³/hour, 24 hours; 3 – 4,5 m³/hour, 8 hours.

Chemistry of the process is following. Lime reacts with water-dissolved carbon dioxide and calcium and magnesium bicarbonates. The process consists of several stages. On the first of these, chemical reactions occur with the formation of molecules of low soluble compounds – calcium carbonate and magnesium hydroxide. The latter form a colloidal system, the enlargement of which to a rough state is the second stage of the process. Then there is an enlargement of coarse disperse formations and removal it from water.

The formation of calcium carbonate and magnesium hydroxide sediment is a complex phenomenon in which combines processes of crystallization of calcium carbonate, sorption of magnesium hydroxide on calcium carbonate crystals, adhesion of crystals coated with magnesium hydroxide, and structure formation.

There is a constant accumulation of sediment, which may have a negative effect on the contact medium, as some part of the sediment "gets old", not reaching the top of the suspended sediment layer, and falls down. Removing the excess of sediment from the contact medium is necessary to maintain the height of the suspended layer of solid particles and to preserve the optimal physical and chemical parameters of the contact medium. Adjustment and preservation of the specified parameters is achieved by removing from the contact medium: inert impurities, aged formations and particles that have the quality to adsorb only one of the components of substances removed from water.

In the clarifiers removing of excessive suspended sediment occurs from the upper part of the layer. In the filters proposed by us, removing of excessive suspended sediment occurs from the bottom of the layer, during the filter washing process.

On the Fig. 6, 7 it's presented height change of suspended sediment layer in column during the filtering cycles with filtering rate 2,5 and 3,5 m³/hour.

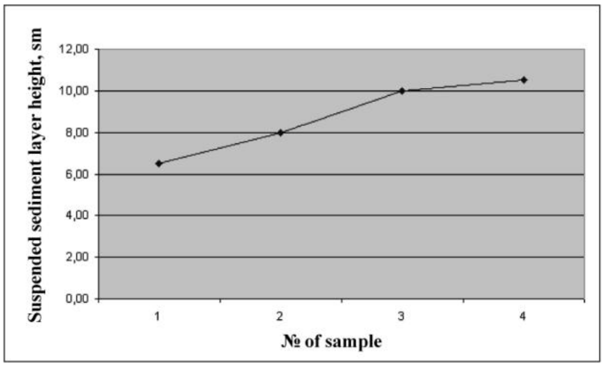

Fig. 6. Height change of suspended sediment layer in column during the filtering cycles with filtering rate 2,5 m³/hour

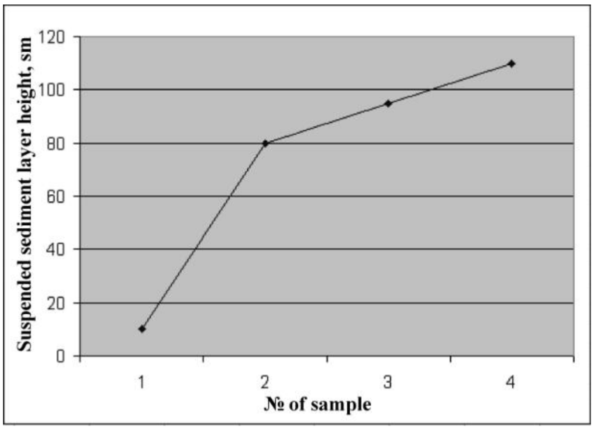

Fig. 7. Height change of suspended sediment layer in column during the filtering cycles with filtering rate 3,5 m³/hour

Also we discovered characteristics of suspended sediment layer. For this purpose we used the method of indirect determination, which is based on the analysis of the results of observation of sediment condensation at a different height of its layer.

On the Fig. 8 it's presented height change in time of suspended sediment sample during the discovering process of characteristics.

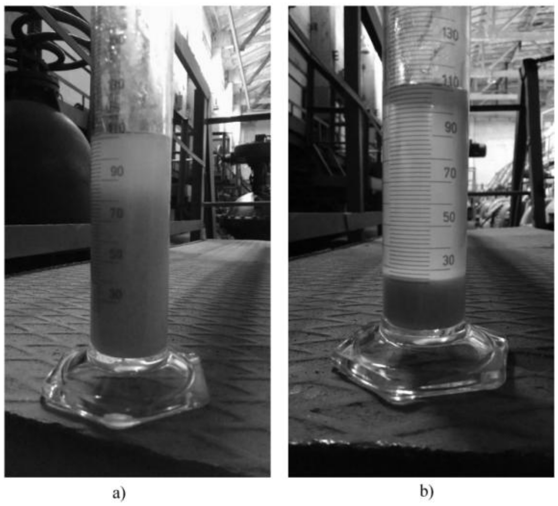

Fig. 8. Height change in time of suspended sediment sample: a) at the beginning; b) in time.

We have calculated the value of such characteristics of suspended sediment:

- solid phase mass – 0,038 g;
- specific concentration – 0,018 g/sm³;
- sedimentation rate – 0,02 sm/s;
- solid phase content by weight in volume unit of unsaturated sediment – 0,00036 g/sm³;
- ratio of water content and solid phase by mass – 378.

The best water softening effect was achieved during filtering cycle with filtering rate – 3,5 m/hour. Results we've reached show ability to use this type of filter for water softening combining with liming method.

Conclusions

One of the most spread reagent treatment method for water softening is liming (Huchler, 2007). Technological scheme for this purpose usually consists of mixer, clarifier and filter. Directly removal of hardness ions takes place in clarifier with suspended sediment. But it has such disadvantages as quite difficult construction and exploitation.

Using expanded polystyrene backfill is well known for clarifying and discoloration and exactly expanded polystyrene filter with increasing layer of suspended sediment – for deferrization.

Using of proposed method - liming on expanded polystyrene filters with increasing layer of suspended sediment, has its advantages:

- reducing effect on water quality: total and calcium hardness, alkalinity;
- simplification of existing water softening technological scheme, excluding clarifiers with suspended sediment;
- simplification of exploitation for staff;
- energy savings, excluding using pumps for backwash;
- is good for industrial water supply use.

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Reviewer: Doctor of Engineering, Professor Victor Kovalchuk, National University of Water and Environmental Engineering, Rivne, Ukraine.

Author: Liudmyla ODUD
postgraduate student,
National University of Water and Environmental Engineering, Rivne, Ukraine.
E-mail – liudmylaodud90@gmail.com
ID ORCID: http://orcid.org/0000-0002-0705-2845

ПІНОПОЛІСТИРОЛ В ТЕХНОЛОГІЯХ ПОМ’ЯКШЕННЯ ВОДИ

Л. М. Одуд
Національний університет водного господарства та природокористування, Рівне, Україна

Продуктивність існуючих споруд для пом'якшення води нижча, ніж проектна. Постає питання знаходження нових, удосконалення сучасних методів пом'якшення води. У статті запропоновано застосовувати пінополістирольні фільтри із зростаючим шаром завислого осаду в технологіях пом'якшення води, поєднуючи з вапнуванням. Отримані результати демонструють чудові перспективи спрощення існуючої технологічної схеми, виключаючи освітлювачі з завислим шаром.

Ключові слова: *жорсткість води, пом’якшення води, пінополістирольне завантаження, завислий шар осаду, метод вапнування*